Final Report
Delivery Order 84, NAS8-38609
Dennis Wingo for Cheryl Bankston
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1.0 Overview of Work Performed

1.1 Background

This work was done in collaboration with the NASA sponsor, Dr. Jeff Luvall of the Space Sciences Laboratory and Dr. Stephen Schiller, of South Dakota State University. The research performed was to determine what suite of on board optics would be required to support space based radiometer with characteristics compatible with the NASA Portable Ground Based Atmospheric Monitoring System (PGAMS) This microsatellite based capability will be a very low cost method of obtaining early data to enable the NASA scientist involved to develop a new and innovative atmospheric corrections technique. This technique will be used in the analysis of surface imagery covering the visible and near-infrared spectral regions. This capability will be available with the delivery to orbit of the SEDSAT 1 satellite in July of 1997 as part of the MSFC developed Small Expendable Deployer System (SEDS). The availability of an effective atmospheric corrections technique in place at the Space Science Lab, MSFC, will also be critical to the support of other future remote sensing projects related to EOS and GEOPLAT.

1.2 Specific Work to be Performed

1. Conduct research regarding the optimal telephoto lens and filter type for and inspace experiment supporting PGAMS spectra output and atmospheric radiance modeling.

2. Conduct a market survey for an optimum lens system that meets the above criteria. Trade off lens types versus compatibility and ease of modification for use on SEDSAT.

3. Modify lens for use on the SEDSAT 1 satellite and integrate with the satellite's other optical and electronic systems.

2.0 Research Accomplished to Support Performance of Task

2.1 Research Regarding Telephoto Lens and Filter Systems

The research conducted was applied to the design of the Students for the Exploration and Development of Space Earth Atmosphere and Space Imaging System (SEASIS). The goal was to find the optimal telephoto lens and filters that would constitute a space based analog to the PGAMS ground based system. Then a market survey was carried out to determine the commercial availability of the target lens and filters. Then the lens was modified and tested for its viability for survival in a space environment. Lastly, the lens system and filters were integrated into the SEASIS imaging system. These tasks were fully accomplished.

First a set of requirements were derived from the literature and personal communications with the PGAMS Principal Investigators regarding data needed to support atmospheric radiance modeling for the particular type system that is PGAMS. These requirements bracketed the scope of the research into what type of telephoto lens and filters that would be compatible with PGAMS. Further requirements were levied due to constraints of mass budget, power and volume available in the SEDSAT 1 satellite. Further constraints also are endemic to the environment that the lens and filters would be exposed to in a space environment.

2.2 SEASIS/PGAMS Studies

Scientists at MSFC and South Dakota State University are implementing a program called the Portable Ground-based Atmospheric Monitoring System (PGAMS) to gather empirical data for calibration and validation of atmospheric corrections algorithms. The results will be applied to correct multispectral and hyperspectral images. Corrections will be made for all significant atmospheric effects, and will depend only on parameters that can be measured from the ground and from the sensor platform at the time the images are acquired.

To make proper corrections, many quantities are needed to characterize atmospheric optical properties for the time and place a remote sensing image is captured. The list includes the extinction coefficient due to molecular scattering; absorption and extinction coefficients of aerosols, water vapor, ozone, and other absorbing gases; aerosol scattering phase function, size distribution, complex index of refraction, single scattering albedo; and, bi-directional reflectance of targeted pixels as well as reflectance contrasts with the scene specific background (adjacency effect)

If all of these quantities are known, then a solution of the radiative transfer equation can be found for the particular image scene, making reliable atmospheric corrections possible. The goal of the PGAMS project, in conjunction with SEASIS, is to obtain data sets sufficient for calibration and validation of atmospheric correction algorithms.

It is widely accepted that atmospheric corrections are more accurate when atmospheric optical parameters are measured as close as possible to the time that a remote sensing image is taken. PGAMS integrates the best available equipment to ensure that a comprehensive set of ground measurements are taken at the same time an overflying sensor, such as SEASIS, is collecting data. Figure 2.1 illustrates the components of the ground based system.

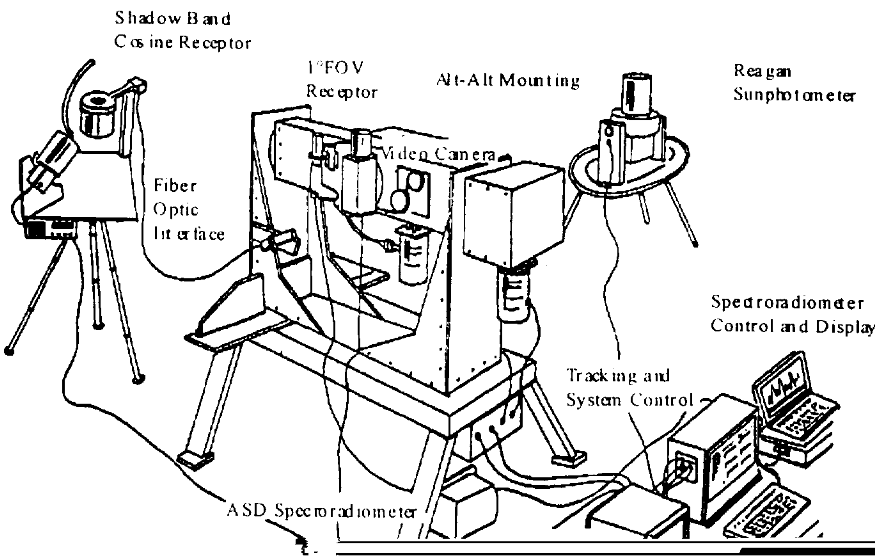

Figure 2.1 PGAMS Ground Based System

PGAMS spectra are gathered via a 512 channel photodiode array spectroradiometer. The instrument samples a spectrum extending from 350 nm to 1050 nm in increments of 1.4 nm, with a FWHM (full-width, half max) resolution of 3 nm. High signal-to-noise is achieved by 12 bit digitization for a dynamic range of 3000 to 1. A tracking system driven by stepper motors provides the spectroradiometer end receptor with an angular pointing resolution of 20 arcseconds. The fore optics consist of a 34 mm focal length lens with a fiber optic bundle placed at the focal plane for signal input. The 0.6 mm diameter of the fiber optic input bundle limits the FOV to 1°, which allows peak signal-to-noise exposures of the path radiance to be recorded in 2 seconds; direct solar irradiance is measured in less than 200 ms. A shadow band cosine receptor interface provides the spectroradiometer with the capability to view the

A sky imaging camera with a 60° FOV is pointed skyward to record images while the spectroradiometer is recording radiance observations. Camera images can be used for identification and extent of clouds and their influence on the radiometric data.

In summary, PGAMS has been developed to obtain a series of *in situ* irradiance, radiance, and reflectance measurements for calibration of atmospheric correction algorithms applied to multispectral and hyperspectral images. While the so-called ground truth measurements acquired by PGAMS can be applied to any algorithm, the precision to which atmospheric effects can be corrected vary with the spectral bandwidth of the images. It is in this area that the images captured by SEASIS, in concert with PGAMS ground truth measurements, are able to provide an enhanced data set for high precision calibration of atmospheric correction algorithms not available with any other existing sensor suites.

2.3 SEASIS Filter Selection

The SEASIS telephoto imaging system will be an integral part of the PGAMS research effort. SEASIS will help to determine the optical properties of the Earth's atmosphere by recording images in 10 specific bands as shown in Table 2.1. The filter selection is optimized to isolate the various atmospheric effects, resulting in a system that will be able to characterize atmospheric effects far beyond the capabilities of what any other existing remote sensing platforms.

The 10 nm bandwidths have been chosen to match PGAMS sun photometer observations; the larger bandwidths in the near IR compensate for the lower detector response for those wavelengths. The 70 nm bandwidth filters at 450, 550, and 650 nm are included for constructing color images with high signal-to-noise ratios .

SEASIS, in conjunction with PGAMS, offers a unique opportunity for high precision calibration and validation of atmospheric correction algorithms. All currently orbiting sensor platforms, such as SPOT, TM, AVHRR, and MSS, as well as those planned for deployment in the near future, are multispectral sensors with an average FWHM of 100m. The larger bandwidths result in multiple atmospheric conditions occurring within the same band. The wavelength dependence of absorption and scattering due to water vapor, aerosols, and ozone makes interpretation of data much more uncertain over larger bands. As shown in Table 2.1, SEASIS bands have been chosen to avoid any coincident affects in a particular band. Additionally, the processor power available with SEASIS makes onboard processing a possibility for calibration of more advanced corrections algorithms. SEASIS could one day provide users of SEDSAT the option to download raw or atmospherically corrected image files.

Atmospheric Parameter	Effective Wavelength	Bandwidth(FWHM)
Aerosol	(Blue) 440 nm	10 nm
Aerosol	(Green) 540 nm	10 nm
Ozone	610 nm	10 nm
Aerosol	(Red) 670 nm	10 nm
Aerosol	780 nm	10 nm
Aerosol	850 nm	40 nm
Water Vapor	950 nm	70 nm

Table 2.1 Filter Wheel Spectral Characteristics

2.4 SEASIS Optical Design

The SEASIS telephoto imaging system will be utilized in concert with the PGAMS ground sensor to record changes in the atmosphere. The lens provides a 7° X 10° FOV yielding an average ground coverage of 50 km X 75 km, with a ground resolution of approximately 100 m per resolvable line pair, depending upon the final altitude and position of the satellite within its orbit. The target ground resolution for the telephoto system was also chosen to ensure proper calibration of the sensor. Ground truth measurements, including ground target reflectance, atmospheric optical depth, solar and sky irradiance and path radiance towards the satellite sensor will be taken periodically to calibrate the system while in orbit. A ground target, with a well known reflectance, must be chosen that covers several pixels on the CCD array. Therefore, the resolution must be high enough to ensure the target fills the pixels. However, if an area is too large, it is not possible to accurately determine the ground truth measurements for the entire area. This leads to uncertainties in the sensor calibration.

The telephoto system relies on a 50 mm focal length, F 1.8 lens . Reports from currently flying imaging systems have shown that a combination of manual iris control and auto iris control are critical to capturing quality images . Therefore, the telephoto lens was equipped with an auto/remote-manual iris and auto/remote-manual average level control (ALC) capabilities. These features are used in conjunction with camera shutter controls to ensure picture quality.

The telephoto lens is a commercial grade Cosmicar product which has been altered for flight by making modifications to the electronics, optics, and lens casing. The electronics modifications included changing the insulated wiring from polyvinyl chloride to Teflon and replacing the electrolytic capacitors with either tantalum capacitors or hermetically sealed electrolytic capacitors. Figure 4.11 shows the telephoto lens before and after modifications were made. Once these modification were completed, the entire lens assembly was dismantled and the optics and the electronics underwent a thermal, vacuum bake-out at temperatures from -20 to + 60. The bake-out was necessary to drive out any volatiles that could occlude the optics in space. Acceptance criteria were based on Hubble Space Telescope bakeout certification parameters . A new lens housing was also machined to facilitate mounting the telephoto system to the satellite.

2.5 Filter Wheel Implementation

Figure 2.2 shows the design of the filter wheel used in the telephoto imaging system. The wheel accommodates 12 equally spaced filters, each having a clear aperture of 0.75 cm diameter. The 1.27 mm diameter, bandpass filters were purchased as "off-the-shelf" items. Since each filter had a different thickness and index of refraction, compensator plates had to be added to equalize the optical path length (OPL) [13]. This step was necessary since the imaging systems are unable to be refocused remotely. As a cost saving measure, the compensator plates were fabricated from cemented layers of cover glass and microscope slides, cored out to 1.27 cm diameter circles. Since the compensator plates are of incremental thicknesses, the OPL of the filters are only approximately equal.

As shown in Figure 2.4, the filter positions are controlled by a 4-phase stepper motor, with 3-1 gear reduction, that is, one step by the motor, corresponding to a shaft rotation of 90°, produces a 30° rotation of the filter wheel, corresponding to one filter position. The filter wheel was machined from Delrin, as opposed to aluminum, to reduce torque on the stepper motor and avoid the need for dampening filter wheel oscillations.

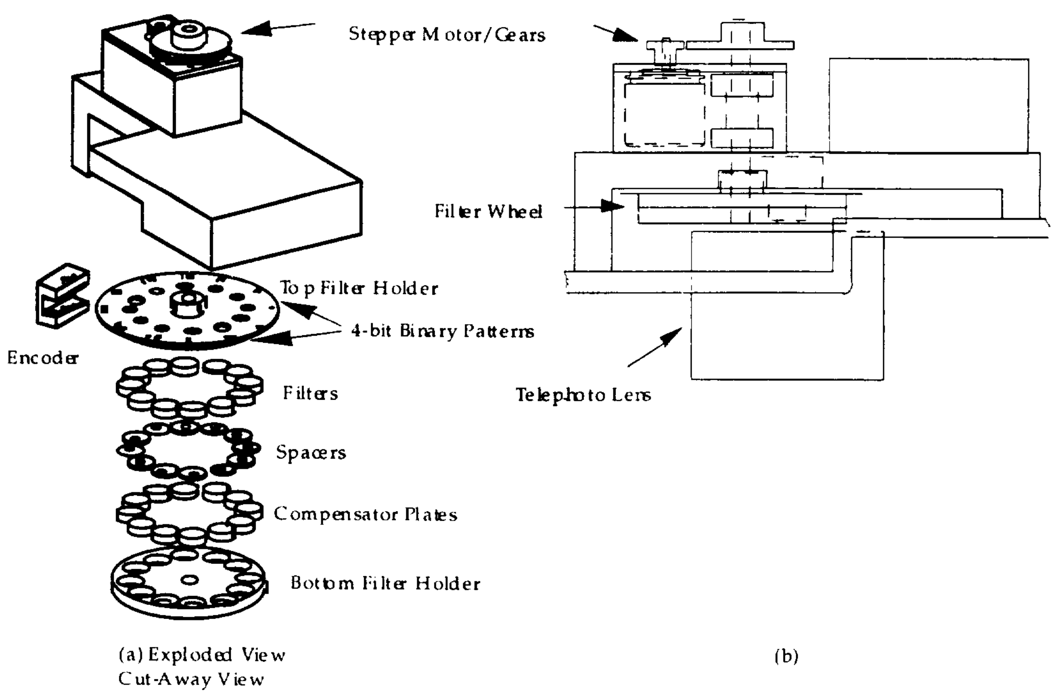

Figure 2.2 Telephoto Imaging System Optical Filter Wheel Design

power and large memory subsystem available with SEASIS will provide users with the ability to perform real-time atmospheric image correction. In addition to studying the atmosphere, the telephoto lens will be used to study surface energy budgets, cloud cover and types, lightning types and frequency, and a number of other Earth resources.

All goals relative to the proposed research were carried out. The SEASIS instrument is in the subsystem integration phase and will fly as part of SEDSAT 1 on STS 85 in July of 1997. The imagery gathered from the instrument will be made available to the NASA investigators on a non-proprietary basis and will be archived at UAH and the University of Arizona for the use of students and atmospheric researchers worldwide.

Dennis Ray Wingo

Submitted by Dennis Wingo for Cheryl Bankston

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Date